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The Zürich Maxi Mental Status Inventory (ZüMAX): Test-Retest Reliability and Discriminant Validity in Stroke Survivors

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Abstract: OBJECTIVE To examine discriminant validity and test-retest reliability of the Zürich maxi mental status inventory (ZüMAX) in patients with stroke. BACKGROUND The ZüMAX is a novel domain-specific cognitive assessment tool to screen for disturbances in neuropsychological function. The test can be used in stroke rehabilitation to estimate severity of cognitive impairment. Because evidence for validity and reliability is lacking, the tool's clinical use is limited. METHODS We administered the ZüMAX in a test-retest design to 33 community-dwelling stroke survivors, and once to 35 healthy controls matched for age and sex. RESULTS We found significant group differences in subscores for the cognitive domains of executive functions and language as well as total score (P=0.001 to 0.004); we did not find group differences for the domains of praxia (defined as the ability to perform purposeful actions), visual perception and construction, or learning and memory. Test-retest reliability of the total score was good (intraclass correlation coefficient=0.81), with the individual domain subscores ranging from poor to fair (0.59 to 0.79). The ZüMAX could detect changes in patients with low smallest detectable differences in executive functions, language, and praxia (0.05 to 1.49) and total score (0.09). CONCLUSION The ZüMAX has moderate to good test-retest reliability. Furthermore, the tool might discriminate between healthy persons and chronic stroke survivors on three of five subscales. The ZüMAX shows promise in measuring neuropsychological disturbances in stroke survivors; however, further trials are required with larger samples.

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The Zürich Maxi Mental Status Inventory (ZüMAX): Test-Retest Reliability and Discriminant Validity in Stroke Survivors

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Objective: To examine discriminant validity and test-retest reliability of the Zürich maxi mental status inventory (ZüMAX) in patients with stroke.

Background: The ZüMAX is a novel domain-specific cognitive assessment tool to screen for disturbances in neuropsychological function. The test can be used in stroke rehabilitation to estimate severity of cognitive impairment. Because evidence for validity and reliability is lacking, the tool's clinical use is limited.

Methods: We administered the ZüMAX in a test-retest design to 33 community-dwelling stroke survivors, and once to 35 healthy controls matched for age and sex.

Results: We found significant group differences in subscores for the cognitive domains of executive functions and language as well as total score ($P = 0.001$ to 0.004); we did not find group differences for the domains of praxia (defined as the ability to perform purposeful actions), visual perception and construction, or learning and memory. Test-retest reliability of the total score was good (intraclass correlation coefficient = 0.81), with the individual domain subscores ranging from poor to fair (0.59 to 0.79). The ZüMAX could detect changes in patients with low smallest detectable differences in executive functions, language, and praxia (0.05 to 1.49) and total score (0.09).

Conclusion: The ZüMAX has moderate to good test-retest reliability. Furthermore, the tool might discriminate between healthy persons and chronic stroke survivors on three of five subscales. The ZüMAX shows promise in measuring neuropsychological disturbances in stroke survivors; however, further trials are required with larger samples.

Key Words: stroke, post-stroke cognitive impairment, domain-specific, test-retest reliability, discriminant validity

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Readers who want to learn more about the ZüMAX or request a research copy can write to Peter Brugger at peter.brugger@usz.ch.

B.C.T.-A. conceived the methodology, collected and analyzed data, assessed quality, and drafted the manuscript. R.H.K. and E.D.deB. supervised study progress and helped to draft and revise the manuscript. P.B. and R.A.deB. helped revise the manuscript.

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ICC = intraclass correlation coefficient. **MMSE** = Mini-Mental State Examination. **MoCA** = Montreal Cognitive Assessment. **SDD** = smallest detectable difference. **SEM** = standard error of measurement. **ZüMAX** = Zürich maxi mental status inventory.

Cognitive impairment is common after stroke. Improving cognition is the highest clinical and research priority after stroke for patients, their caregivers, and health professionals (Pollock et al, 2012, 2014).

Rates of post-stroke cognitive impairment differ widely in the literature, depending on the group studied (eg, hospital-based versus population-based cohorts), criteria for cognitive impairment (eg, with or without pre- or post-stroke dementia or degenerative, vascular, or mixed cognitive disease), and the time between onset of stroke and testing (Blackburn et al, 2013; Brainin et al, 2015; Ihle-Hansen et al, 2011; Jacquin et al, 2014; Makin et al, 2013; Middleton et al, 2014; Sun et al, 2014).

A recent systematic review of domain-specific cognitive impairment in stroke revealed that impaired cognition involved all major cognitive domains (Edwards et al, 2013). To date, however, research evidence is insufficient to support clear recommendations for clinical practice, as post-stroke cognitive impairment is difficult to treat and manage (Gillespie et al, 2015).

The crucial first step in managing cognitive problems is recognition and diagnosis, with baseline cognitive testing for screening or triage. Depending on the results, patients can be offered specialist assessment to define the cognitive problem more precisely (Lees et al, 2013).

Standardized assessment batteries and cognitive screening tools play an important role in identifying underlying cognitive strengths and deficits in survivors of stroke (Van Heugten et al, 2015). Previous studies have provided comprehensive comparisons of the utility and psychometric properties of such tools (Van Heugten et al, 2015). One of the most widely used is the Montreal Cognitive Assessment (MoCA) (Nasreddine et al, 2005). Burton and Tyson (2015) consider the MoCA "the most valid and clinically feasible screening tool to identify stroke survivors with a wide range of cognitive impairments." The Mini-Mental State Examination (MMSE) (Folstein et al, 1975) is widely used for quick dementia screening (Burton and Tyson, 2015).

The MMSE and the majority of other screening tools used to assess post-stroke cognitive impairment were originally developed to assess age-related cognitive decline. Although they are now also used to screen stroke survivors, because of their original purpose, which focused on global impairments, they lack domain-specific items. This might explain why many such tools are unable to detect mild cognitive impairment, an intermediate clinical state that often progresses to dementia (Petersen et al, 1999). Furthermore, there is no consensus on either a preferred tool to test for post-stroke cognitive impairment (Lees et al, 2013) or a preferred timing of assessment (Brainin et al, 2015).

A screening tool for cognition in survivors of one or more left or right hemispheric strokes must first be able to discriminate between healthy people and those who have had a stroke (Chen et al, 2013). Testing discriminant validity for a novel instrument will thus help clinicians interpret stroke survivors' performance.

The growing health care burden, and specifically the social and economic impact of post-stroke cognitive impairment, necessitates further clinical studies that go beyond discriminating between stroke and nonstroke to evaluating assessments and delineating their abilities to discriminate between people with and without post-stroke cognitive impairment. Studies are needed in both acute and long-term settings, to help clinicians plan and provide appropriate treatment throughout a patient's course (Brainin et al, 2015).

The validity of future trials will depend on the ability to describe and quantify cognitive changes in stroke survivors. This ability, in turn, will depend on robust critical evaluations of the cognitive tests given to stroke survivors (Brainin et al, 2015; Quinn et al, 2009), as some commonly used tools may not be suitable for them (Godefroy et al, 2011). Any appropriate test would have to be sensitive to common post-stroke impairments such as difficulties in executive functions; thus, the test should assess different cognitive domains.

A new domain-specific cognitive assessment tool is the Zürich maxi mental status inventory, nicknamed the ZüMAX. It was developed by author P.B. at the Department of Neurology, University Hospital Zürich, in 2012. His goal was to "maximize" the "Mini"-Mental State Examination, to create a neuropsychological screening instrument that would allow a fast (approximately 30 minutes) but highly sophisticated assessment of the cognitive domains of executive function, language, praxia, visuoperception and construction, and learning and memory. Although P.B. designed the ZüMAX to be a quick, convenient first test for patients with suspected neuropsychological deficits of any neurologic origin, the tool is also suitable for long-term follow-up. The actual instrument is described in the *Methods* section.

P.B. modeled the ZüMAX on principles described by Schnider (2004) in his textbook on comprehensive yet time-efficient assessments in behavioral neurology. P.B. also incorporated suggestions from Hachinski et al (2006) that any neuropsychological screening instrument for vascular cognitive impairment include the domains of executive function, language, visuospatial perception and construction, and learning and memory. P.B. added the fifth domain, praxia, defined as the ability to perform purposeful actions, because this domain is typically affected by stroke (Buxbaum and Coslett, 2009).

The ZüMAX has several advantages over both the MMSE and the MoCA. First, the ZüMAX examines the domains of perception and language in greater detail. Second, the ZüMAX tests praxia and executive function; the MMSE does not cover either of these domains, and the MoCA covers only executive function.

The ZüMAX has not yet been published (see "Limitations and Future Directions" in the *Discussion* section). Readers who want to learn more about the tool or request a research copy can write to Peter Brugger at peter.brugger@usz.ch.

The only existing evaluation of the ZüMAX is an unpublished 2014 master's thesis by Andrea Rust at the University of Zürich (Rust, 2014). Rust assessed norms and the construct validity of the ZüMAX compared with the MoCA and MMSE in 227 healthy adults. She found high correlations ($P < 0.001$) between the total scores of all the assessments.

The current study is the first peer-reviewed publication evaluating the ZüMAX. The tool has not been altered, meaning that we used the same version with our stroke survivors that Rust used in 2014.

Our purpose in this study was to evaluate whether the ZüMAX would be a valid and reliable assessment for measuring cognitive impairment in chronic stroke survivors. We aimed to evaluate not only test-retest reliability and smallest detectable difference (SDD), but also differences in scoring between chronic stroke survivors and healthy controls.

We hypothesized that the total score and the subscores for the five cognitive domains would have good relative reliability, with an intraclass correlation coefficient (ICC) ≥ 0.80. Furthermore, we expected the SDDs (absolute reliability) to be $\leq 10\%$ of the mean average values of the total score and subscores for the five cognitive domains. For discriminant validity, we expected to find significant group differences ($P \leq 0.05$) in the total scores and cognitive domain subscores.

METHODS

Participants

To recruit patients who had neurologic deficits after stroke, we contacted 40 outpatient occupational therapy practices in the canton of Bern, Switzerland. We asked the occupational therapists to refer patients currently or recently under their care, and we provided a list of admission criteria for screening the patients. Of the practices we contacted, 23 either had no access to stroke survivors or did not want to participate in the study. The remaining 17 practices, which regularly treated stroke survivors, each referred one to three patients to us between September 2013 and March 2014. (Unfortunately, no data are available about the patients who were approached but refused to participate.) Our study coordinator (author B.C.T.-A.) kept in touch with the participating occupational therapists to discuss the patients' eligibility and guarantee their privacy. Together, the examiner and therapist scheduled the appointments for the examiner to test the patients.

Through these means, we recruited a consecutive community-dwelling sample of 33 stroke survivors who met these eligibility criteria:

- Age older than 18 years
- A stroke diagnosis, confirmed by a physician, at least 6 months before the study
- Ability to speak and understand the German language
- Ability to sit in a chair or wheelchair with a backrest for up to 60 minutes
- MMSE score ≥ 20 (indicating, at worst, mild vascular dementia) for people younger than 80 years of age, and ≥ 16 for people aged 80 years or older (Folstein et al, 1975; Tombaugh et al, 1996)

Exclusion criteria were a diagnosis of a brain injury other than stroke, a physician's earlier diagnosis of neglect or aphasia, and a noncontrolled medical condition such as chronic pain or drug abuse.

We used the Flinders Handedness survey (FLANDERS) (Nicholls et al, 2013) to assess the patients' handedness.

We recruited a consecutive sample of healthy controls, whom we matched to the age and sex of the patients. To find the controls, we handed out participant information sheets to colleagues and relatives of the research team, with a request that they further disseminate the information to other people they knew (snowball sampling). We needed 33 controls, but this method was so successful that 35 people volunteered to take part. Because they fulfilled the inclusion criteria, we included all 35 in the control group.

The eligibility criteria for the controls were:

- Age older than 18 years
- No medical condition (such as a stroke or dementia) that could influence their cognitive skills
- Ability to speak and understand German

We asked the controls about their handedness, but we did not test it.

The study was approved by the Ethics Committee (Kantonale Ethikkommission [KEK]) (KEK-Nr. 119/13) of the Canton of Bern, Switzerland. All participants gave their informed consent before entering the study.

Zürich maxi mental status inventory (ZüMAX)

The ZüMAX is given as an interview. The total administration time of 30 minutes includes 5 minutes of instructions from the examiner. The examiner needs this equipment: a ZüMAX testing form with one coversheet, 24 stimulus cards (chimerical faces), and several demonstration, work, and record sheets; a stopwatch; a metronome; and a plain pencil (no eraser, no ruler) for patients to use.

Before starting the test, the interviewer assesses patients' orientation and obtains their demographic data, including education level. The interviewer also asks patients to score their mood on a visual analogue scale. The ZüMAX includes this "mood scale" (Figure 1) (Regard et al, 1982) because mood has a considerable impact on cognition (Kimura et al, 2000; Narushima et al, 2007).

The ZüMAX profiles the five major cognitive domains typically covered in standard neuropsychological evaluations (Schnider, 2004): language, praxia, learning and memory, visual perception and construction, and executive function. The five domains are assessed in 15 separate tasks, which are given in the following order and some of which we illustrate in this paper:

1. Visual perception: degraded figures, unfamiliar scenes, face
2. Figural fluency (Figure 3)
3. Visuoverbal memory: immediate recall
4. Visuoconstruction: copy figure (Figure 5)
5. Verbal fluency with letter criterion (Figure 3)
6. Visual-spatial memory: draw figure from memory
7. Reading aloud and praxia (Figure 2)
8. Writing, calculation in writing, and oral repetition
9. Category fluency (Figure 3)

10–11. Interference control (two tasks) (Figure 3)

12. Cognitive flexibility (Figure 3)
13. Visuoverbal memory: late recall
14. Nonverbal visual-spatial memory: draw figure again from memory
15. Asymmetry in perception: chimerical faces

As noted, some of the tasks test several domains at once. For example, Figure 2 illustrates a task that assesses both language and praxia. Some tasks require spoken responses, and others require responses written or drawn with pencil and paper, using the dominant hand. Because many of the tasks are timed, the ZüMAX also addresses speed of information processing.

Participants can score a maximum of 6 points in each domain, with a total of 30 points representing optimal function for all five domains. Figure 3 shows the

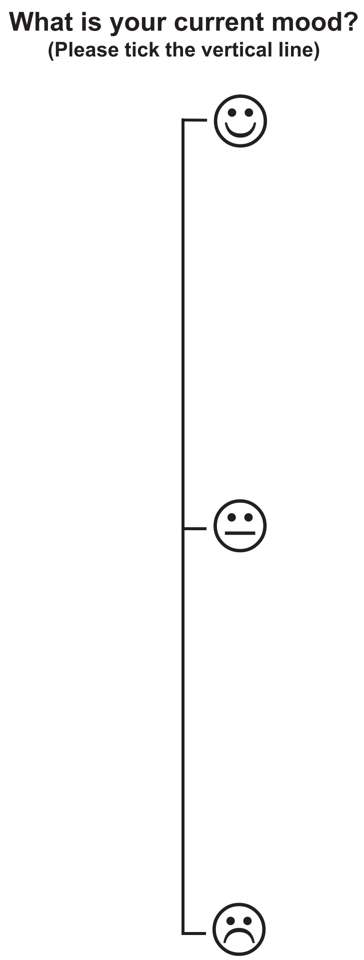


FIGURE 1. Affect: Self-reporting mood scale of the ZüMAX inventory, in English translation. Participants rate both their current mood and their best recollection of their affective state before they suffered their stroke. The examiner rates the value from -6 to +6.

scoring for the domain of executive function and briefly explains the component tasks.

Immediately after completing the ZüMAX, the interviewer notes how long it took and characterizes both qualitatively and quantitatively the patient's orientation, alertness, tempo, ability to cooperate, affect, and communicative behavior.

Procedures

We assessed the patients in the stroke group either at their occupational therapist's clinic or in their home. We tested the patients twice. During the first session, we collected the demographic data and gave the MMSE and the FLANDERS. Then we administered the ZüMAX. As instructed, participants used their dominant hand to perform the writing and drawing tasks. During the second session, we repeated the ZüMAX. We spaced the two sessions about a week apart (mean 6.4 days ± 1.0 standard deviation) to minimize the effect of any learning or memory that might influence a patient's performance on the repeat test.

We did not try to give the patients a thorough neuropsychological evaluation. The patients' treating physician did not request this, and asking for such a service or providing it ourselves would have been beyond our scope.

After finishing the test-retest procedure with a patient, we recruited and tested an age- and sex-matched control participant. We tested the controls at a place of their choosing; most chose their home. At the controls' one testing session, we gathered their demographic data and asked about their handedness. We gave them the ZüMAX only once, to evaluate its discriminant validity.

The examiners were author B.C.T.-A. and master's student Judith Häberli (J.H.). Author P.B. had trained them to administer the ZüMAX. The same examiner did the test and retest of an individual patient. The examiners divided up the testing of the controls depending on their availability.

Statistical Design

We used SPSS version 22.0 (SPSS Inc, Chicago, Illinois) for data management, and MedCalc statistical software version 14.8.1 (http://www.medcalc.org) to draw

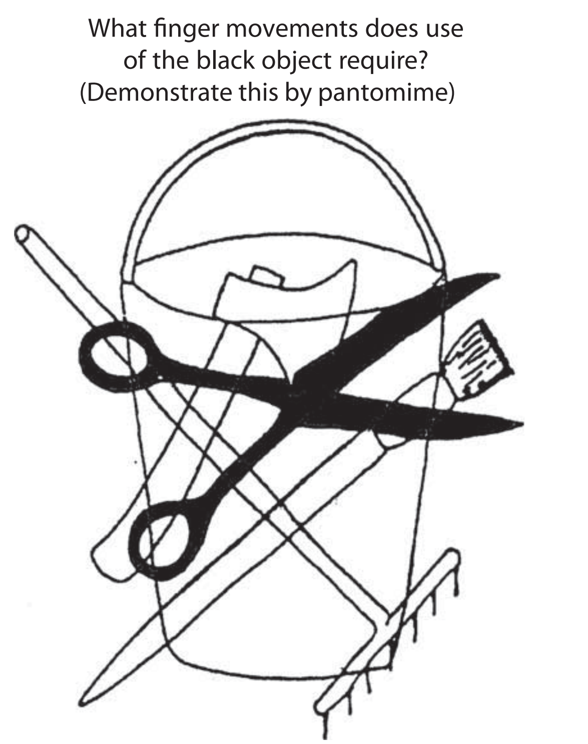
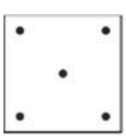


FIGURE 2. Reading aloud and praxia: ZüMAX demonstration sheet for a task in the domains of language and praxia, in English translation. Participants are asked to read the instruction aloud and then act on it. Then they are given four more actions to pantomime, and must act on them.

Enter 1 point in the box for:	Points
Fluency (nonverbal, letter, category)	
Figural fluency in 1 minute: ≥5 correct figures	☐/1
P-words in 1 minute: ≥5 correct words	☐/1
Supermarket items in 1 minute: ≥10 correct items	☐/1
Interference control and response stereotypy	
Digits time ÷ stars time ≤3 AND digits time <30 seconds	☐/1
Digits: ≤2 errors	☐/1
Mental Dice Task: <15 ascended counting steps	☐/1
Subtotal for executive function	**☐/6**

Figural fluency (Regard et al, 1982): 5-point figures: Participants are given a worksheet with 25 boxes, each containing a pattern of five dots, and are asked to draw as many different "figures" as they can in 1 minute. A figure is any straight line connecting 2 or more of the 5 dots. A figure does not need to look good; it just needs to be different from every other figure. After 1 minute, participants are asked to estimate the duration of the task. The examiner checks the worksheet and points out to participants the first repeated figure that they have drawn. Each correct figure counts for 1 point.

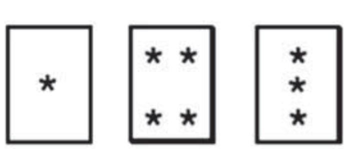


5-point box

Verbal fluency with letter criterion: P-words (Regard et al, 1982): Participants are asked to say as many words starting with the letter "P" as they can in 1 minute. After 1 minute, the examiner asks participants to estimate the duration of the task. The correct words are counted.

Category fluency: supermarket items (Regard et al, 1982): Participants are asked to say as many supermarket items as they can in 1 minute. The correct words are counted.

Interference control: digits and stars (Sedo, 2004): In the first of two tasks, participants are shown a worksheet with 25 boxes, each containing 1 to 5 stars, and are asked to say as quickly as possible how many stars are in each box. In the second task, the participants are shown a sheet with 25 more boxes, each containing 1 to 5 identical digits, and are asked to say as quickly as possible the number of digits in each box. Time is recorded for each trial. Self-corrections are considered errors.



Stars

Digits

Response stereotypy and cognitive flexibility (Brugger et al, 1996): Mental Dice Task: Participants are asked to say the most random possible sequence of numbers, using only the digits 1 to 6, as if they were rolling dice. They are to speak in time with a metronome, at a pace of 1 digit per second. They are stopped after they have said a total of 66 digits. The examiner counts correct digits and notes digits >6 and digits in ascending (eg, 1, 2, 3) and descending (eg, 5, 4, 3) series.

FIGURE 3. Scoring for the ZüMAX executive function domain, in English translation, with task descriptions.

Bland-Altman plots. We set the level of statistical significance at $P \leq 0.05$.

We used descriptive statistics to define the study population and their clinical characteristics. We calculated normality of the data using the Shapiro-Wilk test for small sample sizes (n < 50) (Norman and Streiner, 2008). Our discriminant validity parameters were the subscores for the five cognitive domains and the total test score. We determined testing differences between the stroke and control groups with the Mann-Whitney U test (Norman and Streiner, 2008).

We calculated effect size using the formula for nonparametric tests:

$$r = \frac{Z}{\sqrt{n}}$$

(Z being the converted U score) (Fritz et al, 2012). We then used the effect size estimate r to calculate Cohen d value:

$$d = 2r/\sqrt{(1-r^2)}$$

We calculated the 95% confidence intervals for effect size (Ivarsson et al, 2013). Cohen's (1988) guidelines for d and r are large effect ($d = 0.80$; $r = 0.37$), medium ($d = 0.50$; $r = 0.24$), and small ($d = 0.20$; $r = 0.10$).

We analyzed relative reliability by calculating ICCs separately for single measures using the $ICC_{2(A,1)}$ formula (Shrout and Fleiss, 1979; Weir, 2005). We selected the option "absolute agreement" to take into account the systematic error between raters B.C.T.-A. and J.H. (de Vet et al, 2006). We used the following criteria for reliability: high, 0.90 to 0.99; good, 0.80 to 0.89; fair, 0.70 to 0.79; and poor, ≤ 0.69 (Arnall et al, 2002; Denegar and Ball, 1993).

To calculate absolute reliability, we complemented the ICCs with Bland-Altman analysis, which can be used to show variation or the magnitude of difference of repeated measurements (Rankin and Stokes, 1998). We measured the degree of heteroscedasticity by calculating the Kendall tau correlation between the absolute differences and the corresponding means of the reliability parameter. When we found a positive $\tau > 0.1$, we considered the data to be heteroscedastic. When the Kendall tau was < 0.1 or negative, we considered the data homoscedastic (Brehm et al, 2012). When we found heteroscedasticity, we transformed the data logarithmically (Bland and Altman, 1996; Euser et al, 2008). Then we calculated the Kendall tau again; if $\tau_{\log}$ decreased, we analyzed reliability using the log-transformed parameters (Brehm et al, 2012).

To quantify the precision of individual scores on an assessment, we calculated the standard error of measurement (SEM) with the following formula:

$$\text{SEM agreement} = \sigma\sqrt{(1-\text{ICC})}$$

with σ being the total variance of the scores from all participants (de Vet et al, 2006; Weir, 2005). We then calculated the SDD based on the SEM:

$$\text{SDD} = \text{SEM} \times 1.96 \times \sqrt{2}$$

Here 1.96 defines the 95% confidence interval. The factor $\sqrt{2}$ is included because it concerns the difference between the two measurements.

As a last step, we calculated the SDD %:

$$\text{SDD}\,\% = \frac{\text{SDD}}{\text{grand mean}} \times 100$$

The grand mean is the mean of the means of each ZüMAX parameter. Because agreement parameters (SDDs) are expressed on the actual scale of the assessments, they allow clinical interpretation of the results (de Vet et al, 2006; Weir, 2005). The SDD % can be used to compare test-retest reproducibility among tests (Chen et al, 2009).

RESULTS

All patients and controls completed the study. Table 1 lists the participants' demographic and clinical characteristics. Of our 33 stroke survivors, 29 (87.8%) had suffered one stroke and four (three men and one woman) (12.1%) had sustained at least two strokes.

Table 2 presents the two study groups' ZüMAX scores, including the total testing time and scores for self-evaluation of mood. The results of the Shapiro-Wilk test (Norman and Streiner, 2008) showed no normal distribution.

Discriminant Validity

In addition to the ZüMAX results, Table 2 presents the group differences. Descriptive statistics showed that the controls scored higher in all five cognitive domains and in the total score. For example, for the domain executive function, the patients' median and mean rank scores were 5 and 28.3 versus the controls' 6 and 40.3. The Mann-Whitney U value was significant: $U = 369.5$ ($Z = 0.29$), $P = 0.004$. The difference between groups was small: effect size $r = 0.04$; $d = 0.08$.

Overall, we found a significant difference between the two groups in three of the six measures: executive function, language, and total test score (P-values ranging from 0.001 to 0.004). The other three domains (praxia, visual perception and construction, and learning and memory) had no significant differences between the groups ($P = 0.075$ to 0.386). We found a small to medium effect size in the cognitive domains (r ranging from 0.04 to 0.22; d from 0.08 to 0.44) and a large effect size for the total score ($r = 0.40$, $d = 0.95$).

Test-Retest Reliability

Table 3 shows the test-retest reliability of the ZüMAX for the stroke group, and Figure 4 illustrates the findings in Bland-Altman plots.

TABLE 1. Demographic and Clinical Characteristics of the Stroke and Control Groups

		Stroke (n = 33)	Control (n = 35)
Sex (n [%])	Women	9 (27.3)	9 (25.7)
	Men	24 (72.7)	26 (74.3)
Age (years)	Mean ± standard deviation	63.2 ± 14.7	63.0 ± 14.6
	Median (range)	66 (33 to 89)	67 (33 to 85)
Education (n [%])	University education	6 (18.2)	20 (57.1)
	Apprenticeship	24 (72.7)	15 (42.9)
	No completed education	3 (9.1)	0 (0)
Stated handedness (n [%])	Right	22 (66.7)	33 (94.3)
	Mixed	0 (0)	0 (0)
	Left	11 (33.3)	2 (5.7)
Handedness according to Flinders Handedness Survey[1] (n [%])	Right (+5 to +10 points)	22 (66.7)	
	Mixed (−4 to +4 points)	1 (3.0)	
	Left (−10 to −5 points)	10 (30.3)	
Affected hand (n)	Right	19	
	Left	14	
Affected hand = dominant hand (n [%])		20 (66%)	
Forced to use nondominant hand because of stroke (n)		8	
Months since onset of stroke	Mean ± standard deviation	49.4 ± 79.8	
	Median (range)	22 (6 to 387)	
Hemisphere affected by stroke (n [%])	Left	19 (57.6)	
	Right	14 (42.4)	
Mini-Mental State Examination[2] score (maximum, 30 points; ≥ 24 points = normal[3])	Mean ± standard deviation	27.4 ± 2.3	
	Median (range)	28 (18 to 30)	

[1]Nicholls et al, 2013. [2]Folstein et al, 1975. [3]Burton and Tyson, 2015.

Our first hypothesis, about relative reliability (ICC ≥ 0.80), was confirmed by virtue of the ZüMAX total score having an ICC of 0.81 (95% confidence interval: 0.64 to 0.90) (Table 3). For subscores, the ICCs ranged from fair for executive function, language, and praxia (ICC = 0.72 to 0.79), to poor for visual perception and construction (0.59) and for learning and memory (0.60).

Our second hypothesis, concerning absolute reliability, was supported in four of the six ZüMAX measures: The SDDs for executive function, language, praxia, and total score (ranging from 0.05 to 1.49) were all ≤ 10% of the mean average values of the total score and subscores (Table 3). The SDDs of the two cognitive domains visual perception and construction (SDD = 2.16) and learning and memory (SDD = 1.97) exceeded the expected 10%, forcing us to reject the hypothesis. Calculating Kendall tau revealed that the three measures (executive function, praxia, and total test score) were heteroscedastic and therefore needed to be logarithmically transformed (Table 3).

DISCUSSION

This study evaluated the discriminant validity and test-retest reliability of the novel cognitive assessment "ZüMAX" in survivors of stroke.

Validity

In the discriminant validity parameters with significant group differences, the stroke group scored on average 0.7 point lower than the controls for the domain language, 0.9 point lower for executive function, and 2.7 points lower for the total test score (Table 2). These results correspond in part to those of Kaya et al (2014), who compared MoCA scores for 114 patients with mild cognitive impairment and 246 healthy controls. The authors reported that the most useful domains in discriminating mild cognitive impairment from normal cognition were recall, visuospatial, and language.

In the ZüMAX, however, the differences between groups were nonsignificant: only 0.1 point for praxia and 0.5 point each for visual perception and construction and for learning and memory. It is possible that by the time we

TABLE 2. ZüMAX Scores and Statistical Differences Between the Stroke and Control Groups

Domain (Maximum Points)	Unit	Stroke (n = 33) Test	Stroke (n = 33) Retest	Control (n = 35) Test	*Z*-score	Mann-Whitney *U* Test (*P* = 0.05)	Effect Size *r* and *d* (95% Confidence Interval)
					Stroke Versus Control		
Executive function (6)	Mean ± SD	4.7 ± 1.4	5.0 ± 1.3	5.6 ± 0.7	0.29	0.004	0.04 (–0.20 to 0.28)
	Median (range)	5 (1 to 6)	5 (2 to 6)	6 (3 to 6)			0.08 (0.04 to 0.12)
	Mean rank	28.33	NA	40.31			
Language (6)	Mean ± SD	5.1 ± 1.1	5.1 ± 1.2	5.8 ± 0.5	2.95	0.003	0.04 (–0.20 to 0.28)
	Median (range)	5 (2 to 6)	5 (1 to 6)	6 (4 to 6)			0.08 (0.04 to 0.12)
	Mean rank	28.33	NA	40.31			
Praxia (6)	Mean ± SD	5.8 ± 0.5	5.8 ± 0.4	5.9 ± 0.3	0.87	0.386	0.11 (–0.13 to 0.35)
	Median (range)	6 (4 to 6)	6 (5 to 6)	6 (5 to 6)			0.22 (0.18 to 0.26)
	Mean rank	33.30	NA	35.63			
Visual perception and construction (6)	Mean ± SD	4.7 ± 1.4	5.1 ± 1.1	5.2 ± 0.9	1.50	0.134	0.18 (–0.06 to 0.42)
	Median (range)	5 (0 to 6)	5 (1 to 6)	5 (3 to 6)			0.37 (0.33 to 0.41)
	Mean rank	31.00	NA	37.80			
Learning and memory (6)	Mean ± SD	5.4 ± 1.2	5.6 ± 1.1	5.9 ± 0.4	1.78	0.075	0.22 (–0.02 to 0.46)
	Median (range)	6 (2 to 6)	6 (1 to 6)	6 (5 to 6)			0.44 (0.40 to 0.48)
	Mean rank	31.32	NA	37.50			
Total score (30)	Mean ± SD	25.7 ± 3.9	26.6 ± 3.4	28.4 ± 1.9	3.33	0.001	0.40 (0.16 to 0.64)
	Median (range)	26 (14 to 30)	28 (13 to 30)	29 (23 to 30)			0.95 (0.91 to 0.99)
	Mean rank	26.42	NA	42.11			
Test duration (minutes)	Mean ± SD	33.8 ± 6.6	28.6 ± 6.2	28.7 ± 6.5			
	Median (range)	35 (20 to 50)	30 (20 to 40)	30 (20 to 50)			
Self-evaluation of mood (scale from –6 to 6)	Mean ± SD	3.9 ± 2.2	4.2 ± 2.3	4.4 ± 1.3			
	Median (range)	4 (–1 to 6)	5 (–1 to 6)	5 (1 to 6)			

NA = not applicable. **SD** = standard deviation.

recruited our sample of stroke survivors, they had already recovered almost completely in these domains and thus reached near-perfect scores, creating a ceiling effect.

A test is considered to have floor or ceiling effects if > 15% of the respondents score the minimum or maximum (Terwee et al, 2007). When we checked for such effects in the ZüMAX, we found no floor effects but we saw ceiling effects in all three cognitive domains with nonsignificant group differences. For praxia, for example, 84.9% of our stroke group scored the full 6 points, as did 91.4% of the controls. For the total score, 34.3% of the controls scored the full 30 points (and 25.7% reached 29 points), while only 6.1% of the stroke sample scored the maximum (and 30.3% reached 29 points). These ceiling effects make it impossible to distinguish among participants who had perfect scores, indicating limited validity.

Still, it seemed important for the ZüMAX to have a maximum of 6 points for each of the five relevant neuropsychological domains. This would make the total scale score of 30 points comparable to other cognitive screening instruments, especially the MMSE and MoCA, both of which also have a maximum score of 30. Before this scoring is made final for the ZüMAX, however, the scale should be examined in larger samples of stroke survivors and healthy controls, correcting for possible confounding factors such as cognitive status, to find out if ceiling effects remain.

We found that our stroke group needed on average of 5.1 minutes longer than the controls to perform the ZüMAX (Table 2). Needing more time to complete an assessment requires a longer period of concentration, disadvantageous in a population most of whose members

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TABLE 3. Test-Retest Reliability of the ZüMAX Subscores and Total Score in the Stroke Group (n = 33)

				Kendall Tau				
Domain (Maximum Points)	**Test Mean ± SD**	**Retest Mean ± SD**	**Test-Retest Mean Difference ± SD**	**Correlation**	**Correlation with Log-Transformed Data**	**Intraclass Correlation Coefficient (95% Confidence Interval)**	**Standard Error of Measurement Agreement**	**Smallest Detectable Difference No. (%)**
Executive function (6)	4.7 ± 1.4 **0.7 ± 0.2**	5.0 ± 1.3 **0.7 ± 0.1**	– 0.24 ± 0.97	0.30*	0.16†	0.73 (0.53 to 0.86) **0.78 (0.60 to 0.88)**	0.69 **0.08**	1.92 (39.48) **0.21 (31.72)**
Language (6)	5.1 ± 1.1	5.1 ± 1.2	– 0.03 ± 0.77	0.96*	0.99	0.79 (0.62 to 0.89)	0.53	1.49 (28.99)
Praxia (6)	5.8 ± 0.5 **0.8 ± 0.04**	5.8 ± 0.4 **0.8 ± 0.03**	– 0.03 ± 0.30	0.15*	0.14†	0.74 (0.53 to 0.86) **0.72 (0.50 to 0.85)**	0.21 **0.02**	0.59 (10.08) **0.05 (6.54)**
Visual perception and construction (6)	4.7 ± 1.4	5.1 ± 1.1	– 0.36 ± 1.08	0.05	NA	0.59 (0.31 to 0.77)	0.78	2.16 (44.49)
Learning and memory (6)	5.4 ± 1.2	5.6 ± 1.1	– 0.21 ± 1.00	0.05	NA	0.60 (0.34 to 0.78)	0.71	1.97 (35.89)
Total score (30)	25.7 ± 3.9 **1.4 ± 0.08**	26.6 ± 3.4 **1.4 ± 0.07**	– 0.88 ± 2.25	0.26*	0.24†	0.79 (0.61 to 0.89) **0.81 (0.64 to 0.90)**	1.66 **0.03**	4.61 (17.65) **0.09 (6.37)**

Bold type indicates log10-transformed heteroscedastic parameters.
*τ > 0.1 indicates heteroscedastic data.
†τ_{log} decreased.
SD = standard deviation. **NA** = not applicable (because τ < 0.1).

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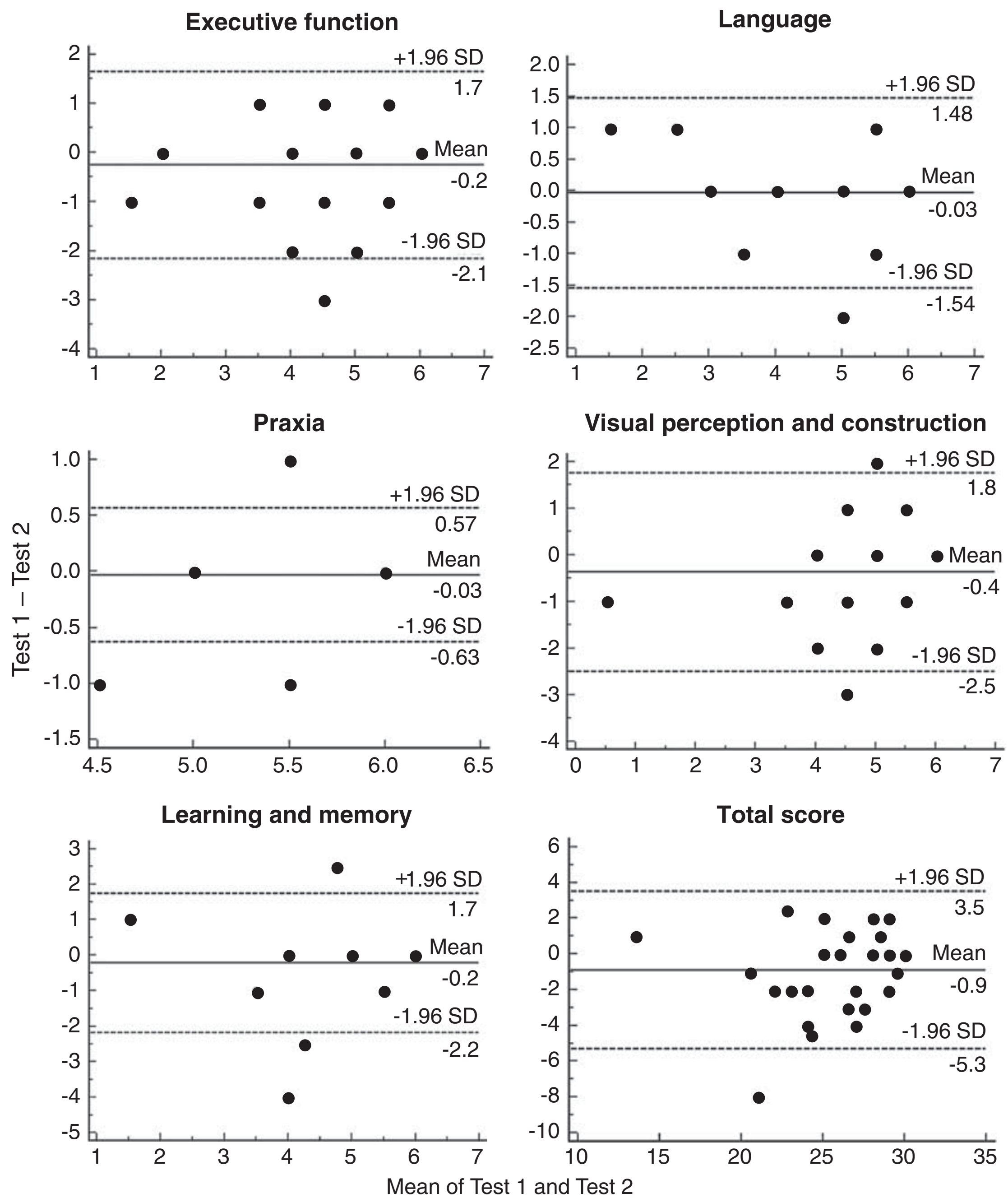

FIGURE 4. Bland-Altman plots of the five ZüMAX cognitive domain subscores and total score. The plots for executive function, praxia, and total score showed a heteroscedastic data distribution, and therefore needed to be transformed logarithmically for further analysis. Because many of the 33 stroke survivors shared the same score, fewer than 33 data points are visible in each plot; the overlap is most obvious in the praxia plot, which has only 5 data points, all falling between 4 and 6 (mean = 5.8 points) in the test and retest. The plots for executive function, visual perception and construction, learning and memory, and total score all showed a trend toward a slight improvement on the retest. Almost all domains had visible within-group differences, with outliers.

likely have cognitive deficits (Van Heugten et al, 2015). One reason for the prolonged test could be impairments in patients' information processing speed, a domain often affected after stroke (Edwards et al, 2013; Middleton et al, 2014). Another reason is that 66% of our stroke sample had to perform the ZüMAX writing tasks using their affected hand as the dominant hand.

Furthermore, the stroke group self-rated their mood an average of 0.5 point lower than the controls (Table 2). There is evidence that mood can affect cognition and that

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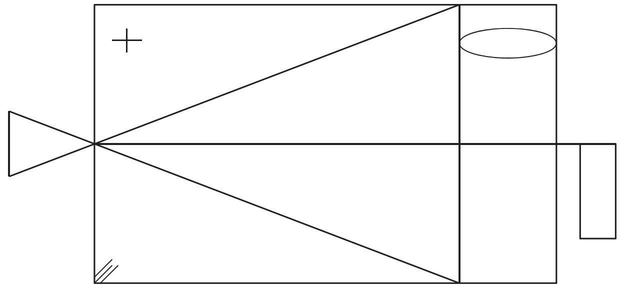

FIGURE 5. Visuoconstruction and speed of information processing: ZüMAX worksheet for a task in the domain of visual perception and construction, in English translation. Participants are asked to copy the geometric figure as accurately as they can and to memorize it for later. They are told that "beauty doesn't matter." What does matter is that they draw the entire figure with all the parts in the right places and in approximately correct proportions. Participants earn one point for each of these elements: (1) the big rectangle, (2) a correctly placed small triangle, (3) the horizontal middle line, (4) the small rectangle on the far right side, (5) the "plus" sign in the upper left corner, (6) the three small diagonal lines in the lower left corner, (7) the oval, (8) the vertical line tangent to the left side of the oval, (9) the lower diagonal line, and (10) the upper diagonal line. One point is deducted for each markedly displaced or confabulated added element.

depression is quite common after stroke (Kimura et al, 2000; Narushima et al, 2007). This might explain our stroke sample's lower self-assessment on the mood scale and their slowed and less accurate test performance.

It is also well known that education has a main effect on cognitive assessment scores, while sex does not (Kaya et al, 2014). We suggest correcting the ZüMAX for education effects, eg, by adding one point to the total score of participants who have at most 12 years of education, as is done with the MoCA (Nasreddine et al, 2005; Pendlebury et al, 2010).

In our study, the control group was much more educated than the patients (Table 1). We were unable to correct for these education differences, however, for two main reasons. First, our older participants in particular could not remember exactly how many years of education they had, and we were reluctant to include estimations in our study. Second, most participants, especially those with a university degree or apprenticeship, shared an attitude of life-long learning and had attended several continuing education programs, thus making it impossible for us to determine a true cutoff for years of education. To address this problem, we recommend considering education in the inclusion criteria of future studies.

Reliability

The ZüMAX showed fair to good reliability in four of the six measures, the exceptions being the domains visual perception and construction (ICC = 0.59) and learning and memory (ICC = 0.60). In the visual perception and construction domain, copying a 10-element figure (Figure 5) may have been subject to learning effects despite our effort to prevent them by spacing the test and retest about a week apart. Likewise, in the learning and memory domain, the break between test sessions may not have been long enough to prevent a learning effect.

The other three cognitive domains (executive function, language, and praxia) and the total score, all of which had fulfilled our first hypothesis, had generally good test-retest reliability. Their low SDDs indicate that the ZüMAX is sensitive to individual change (Lexell and Downham, 2005).

Our ICCs were lower than those of other cognitive assessments, eg, the MoCA. The MoCA's test-retest reliability for patients with cerebrovascular disease was good, ranging from 0.75 to 0.96 (Tu et al, 2013). However, it is unclear which ICC formula Tu and colleagues applied in their statistics. This might be of importance in interpreting the results, as we used single measures (ICC 2,1 formula) to calculate our ICCs, which might have given us lower ICCs than if we had used averages for calculation (eg, ICC 2,k formula) (Shrout and Fleiss, 1979; Weir, 2005).

Limitations and Future Directions

Our study had some limitations. First, we should emphasize that conclusions about the sensitivity of the ZüMAX must await larger investigations that include both a population with cognitive deficits and a comparable population of matched healthy participants.

Second, we could have used stricter inclusion and exclusion criteria to minimize heterogeneity between and within the stroke and control groups. For example, stricter criteria could distinguish between survivors of a first-ever or a recurrent stroke, as well as among patients with different subtypes of mild cognitive impairment (vascular, degenerative, mixed). With stricter criteria, we could also stratify the sample by age group, education level, or time since stroke onset, and we could consider pre-stroke cognitive decline (Brainin et al, 2015).

Third, accessing and assessing our patients' exact stroke diagnosis and medical history was difficult because some of the patients had suffered their stroke many years earlier.

A possible final limitation was our small sample size, which may have affected the values of reliability and measurement error. While the guidelines by Kottner et al (2011) would consider a sample size of 50 as adequate for our purpose, we think that our sample of 33 patients was of reasonable size in this first attempt to evaluate the general usefulness of the ZüMAX in patients with chronic stroke.

We see several directions for future research. One idea is to evaluate the value of the ZüMAX for patients during the acute phase of their stroke, or for an entirely different population, such as people with traumatic brain injury.

Cutoff scores have not yet been established for this novel instrument, unlike other similar tools such as the MMSE ($\geq$24 points = normal according to Burton and Tyson, 2015) or the MoCA ($>$26 points = normal)

(Dong et al, 2010; Nasreddine et al, 2005). More work is required here.

It would also be valuable to evaluate the ZüMAX's ecological validity, defined as the degree to which results obtained under experimental conditions relate to those obtained in natural environments (Tupper and Cicerone, 1990). Chaytor and Schmitter-Edgecombe (2003) reviewed the research on ecological validity of neuropsychological tests, and concluded that many instruments offer moderate ability to predict patients' everyday cognitive function; the limitation of many tests is that they do not target individual cognitive domains that reflect specific aspects of daily function. However, it is unclear from the literature how strong the relationship between neuropsychological tests and measures of everyday function should be for a test to be considered ecologically valid.

To extend its reach, the ZüMAX could be digitized and integrated into a virtual exercise program for stroke survivors, allowing them to follow their progress when exercising independently at home so that they could further improve their upper limb motor and cognitive skills.

Finally, to increase awareness of the ZüMAX among clinicians, the tool should be translated into other languages. As of May 2016, author P.B. had written an English-language version of the test manual for clinicians, and he was planning a German-language publication on normative data for the ZüMAX in healthy adults. Author B.C.T.-A. had been involved with a Spanish-language translation, which was being tested in stroke survivors in Seville, Spain. There was no plan to publish the original German-language version of the test and manual.

In summary, the ZüMAX is a brief, yet comprehensive, domain-specific cognitive assessment for measuring disturbances of neuropsychological function in patients with chronic stroke. The instrument shows moderate to good reliability. In this preliminary study, the total test score showed better results than the subscores for the five single cognitive domains measured. The domains of executive function, language, and praxia showed fair reliability; the domains of learning and memory and of visual perception and construction showed poor reliability. As for discriminative validity, the ZüMAX might discriminate chronic stroke survivors from healthy controls on the three subscales of executive function, language, and learning and memory, as well as on the total score. In conclusion, our study indicates that the ZüMAX can be used as a single direct assessment to provide a "snapshot" of the current state of cognition in survivors of chronic stroke, but further research is required with larger sample sizes.

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